*International Journal of Bioelectromagnetism*
Vol. 5, No. 1, pp. 256-257, 2003.

*www.ijbem.org*

# On Using ECGSIM

**A. van Oosterom and T.F. Oostendorp**

*Department of Medical Physics, University of Nijmegen, The Netherlands*

Correspondence: A van Oosterom, Dept. Medical Physics, University of Nijmegen, Geert Grooteplein 21, 6525EZ Nijmegen, The Netherlands. E-mail: avo@mbfys.kun.nl, phone +31.24.3614248, fax +31.24.3541435

***Abstract.*** ECGSIM is a simulation program that has been deviced to allow its user to interactively change the timing of depolarization and repolarization on the ventricular surface as well as the local source strength and study the effect of such changes on electrograms on the heart surface as well as on body surface potentials. It aimes at being a research tool as well as a teaching tool for those interested in the basic aspects of the genesis of the electrocardiogram. Some of its major features are discussed. The simulation package is available at: www.ecgsim.org.

*Keywords:* Interactive Simulation; QRST Wave Forms; Equivalent Double Layer

## 1. Introduction

The development of diagnostic ECG criteria has been accompanied by the development of biophysical models aimed at linking the electrophysiology of cardiac function to the waveforms of the ECG signals observed on the body surface. The need for the use of models stems from the fundamental impossibility of deriving a unique specification of internal bioelectric sources on the basis of observations of the potentials on the body surface: a multitude of different source give rise to identical data outside the actual source region. Invariably, two models are involved: a model of the bioelectric generator, i.e. a source model, and a model for describing the effects on the observed signals of the body tissues that surround the active electric sources: a volume conductor model. The simulation program ECGSIM allows the user to interactively change the timing of depolarization and repolarization on the ventricular surface as well as the local source strength and study the effect of such changes on electrograms on the heart surface as well as on body surface potentials. The theory behind the forward computation is outlined here only briefly, focussing on the aspects of the source parameters that can be changed interactively. The announcement of the official release of the package through the internet has been submitted to *Heart*.

## 2. Theory

The source model used in the simulation is the equivalent double layer (EDL). It expresses the entire electrical activity within the ventricles by means of a double layer source situated on the closed surface $S_V$ bounding the ventricular myocardium. For any position on $S_V$ the time course of the local source strength is taken to be proportional to the transmembrane potential of the cells near $S_V$. For the depolarization phase the EDL has a direct link with the classic uniform double layer (UDL), located at the depolarization wave front. This follows from the application of the solid angle theory [Cuppen and van Oosterom 1984; van Oosterom 2002]. The extension of the UDL to the T wave is a more recent development [Geselowitz 1989, 1992; van Oosterom 2001,2002a].

Two transfer matrices were computed: the transfer between the EDL elements and the potentials on $S_V$ and the transfer between the elements of the EDL and the potentials on the thorax surface. These matrices were computed by applying the Boundary Element Method to the geometry of the torso and that of the relevant conductivity interfaces, measured by means of magnetic resonance imaging. The model takes into account the relatively low conductivity of the lungs and the relatively high conductivity of blood in the ventricular cavities[Huiskamp and van Oosterom 1988].

## 3. Methods

The source model applied in ECGSIM is the EDL as discussed above. The surface $S_V$ was discretized by small triangles, the *N* vertices (nodes) of which (*N*=257) served to specify the locations of the equivalent double layer elements. For any position on $S_V$ the time course of the local double layer strength is taken to be proportional to the transmembrane potential of the cells near the boundary.

The time course of the source strength of any node *n* is assigned the shape of the transmembrane potential specified at 1 ms intervals. The general shape of this curve was taken to be identical for all nodes. Its downward part was derived from a weighted mean of the measured ECG during the T wave [van Oosterom 2002a]. The timing of local depolarization (taken to be the moment of maximum slope of the upstroke) at node *n* of $S_V$ is denoted as $d_n$. Similarly, the time instant of the maximum negative slope is taken as a marker for the timing of local repolarization. For node *n* it is denoted as $r_n$. The interval $a_n = r_n - d_n$ is a measure of the local action potential duration (APD).

The magnitudes of the upstroke of the local transmembrane potential, for node *n* denoted by $m_n$, are used to specify local source strength. The default settings of these values are at a uniform maximum.

ECGSIM has default settings for the parameters $d_n$ and $r_n$. These were found by means of an inverse procedure applied to measured body surface potentials [Cuppen and van Oosterom 1984; Huiskamp and van Oosterom 1988, van Oosterom 2001]. The default setting for the source magnitude $m_n$ is 100%, corresponding to uniform magnitude of the upstroke of the action potential. By reducing the source strength at node *n* the effect of, e.g., local ischemia on body surface potentials may be studied. The distribution of each type of source parameters ($d_n$ , $r_n$ , $a_n$ or $m_n$ ) may be viewed on $S_V$.

The simulated potentials at both the heart surface and on the body surface may be viewed as waveforms (electrograms and/or QRST complexes), potential maps or movies. A set of measured body surface potentials is provided as a reference.

## 4. Using ECGSIM

Starting from their default setting any of the source parameters, at any of the nodes, may be varied; the effect of this on heart and body surface potentials is visible instantaneously.

While changing the value of a node parameter value, the values at the surrounding nodes may be set to change by a factor that decreases with distance. The distance involved (corresponding to, e.g., the extent of an ischemic region) may be set interactively, and may be chosen to be effective either over the surface that carries the node operated on, or throughout the myocardium. In this way epicardial, endocardial or changes involving regions, of different extent, on both endocardium and endocardium may be induced.

Another option for manipulating the parameters is to modify their overall statistics: mean and standard deviation. Examples of the usefulness of this option are the study of the expression of the dispersion of the source parameter values, e.g. APD, on body surface potentials (QT dispersion) or the expected changes in T wave morphology associated with the long QT syndrome.

Parameter settings adapted during a session, as well as the resulting potentials, may be stored for subsequent processing outside ECGSIM. These stored sets may also be reloaded for subsequent use in ECGSIM.

## 5. Conclusion

By comparing the simulations to the measured data it can be seen that the quality of the simulation is high. We feel confident that this package will be of great practical use to others studying or teaching the basic properties of the genesis of the QRST waveforms.

**References**

Cuppen JJM, vanOosterom A. Model studies with the inversely calculated isochrones of ventricular depolarization. *IEEE Trans Biomed Eng*., BME-31: 652-659, 1984.

Geselowitz DB. On the Theory of the Electrocardiogram. *Proceedings IEEE*, vol. 77(6): 857—876, 1989.

Geselowitz DB. Description of cardiac sources in anisotropic cardiac muscle. Application of bidomain model. *J. Electrocardiology*, 25S: 65-67, 1992.

Huiskamp GJM, van Oosterom A. The depolarization sequence of the human heart surface computed from measured body surface potentials. *IEEE Trans. Biomed. Eng*.; BME-35: 1047-1058, 1988.

van Oosterom A. Genesis of the T Wave as Based on an Equivalent Surface Source Model. *J. Electrocardiology*, 34S: 217-227, 2001.

van Oosterom A. Solidifying the Solid Angle. *J. Electrocardiology*, 35S: 181-192, 2002.

van Oosterom A. The Equivalent Surface Source in its application to the T wave. In: Pastore CA, ed. Electrocardiology '02. Singapore: World Scientific, 2002a: 527-535.

<="" p="" style="font-family: "Times New Roman", Times, serif; font-size: 10pt; text-align: justify;">